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EVALUATION OF ROAD EXPANSION AND CONNECTIVITY MITIGATION FOR WILDLIFE IN SOUTHERN CALIFORNIA

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Abstract—We designed a remote-camera survey to study how the expansion of California State Route 71 (CA-71) and implementation of connectivity mitigation affected the use of underpasses by large mammals in southern California. Based on detections by cameras, the use of underpasses by bobcats (*Lynx rufus*) was higher within the area of expansion and mitigation after construction than before, but there was no difference in use of underpasses in the impact zone compared to the control zone before or after construction. Use of underpasses by coyotes (*Canis latrans*) was higher in the control zone than in the impact zone, but there was no difference in use before and after construction. Small numbers of detections of mule deer (*Odocoileus hemionus*) at only a few underpasses precluded comparison between control and impact zones. However, a comparison of use before and after construction revealed that use of underpasses by mule deer was slightly higher post-construction. We cannot fully attribute increased detections post-construction to mitigative efforts, because other factors, such as availability of habitat, urbanization, or demography, also may have influenced use of underpasses along CA-71. Nonetheless, even with the expansion of the freeway and subsequent increase in volume of traffic, mitigative structures along CA-71 did allow for continued movement and, hence, connectivity across the roadway for large mammals.

Resumen—Diseñamos un monitoreo de cámara remota para estudiar cómo la expansión de la ruta estatal de California 71 (CA-71) y la implementación de medidas de mitigación de conectividad afectaron el uso de pasos inferiores por los mamíferos grandes en el sur de California. Basado en las detecciones por las cámaras, el uso de los pasos inferiores por los linces (*Lynx rufus*) fue mayor dentro de la zona de expansión y mitigación después de la construcción que anteriormente, pero no hubo ninguna diferencia en el uso de los pasos inferiores en la zona de impacto en comparación con la zona de control antes o después de la construcción. El uso de pasos inferiores por los coyotes (*Canis latrans*) fue mayor en la zona de control que en la zona de impacto, pero no hubo diferencia en el uso antes y después de la construcción. Un pequeño número de detecciones de venados buras (*Odocoileus hemionus*) en sólo unos pocos pasos inferiores excluyó la comparación entre las zonas de control y de impacto. Sin embargo, una comparación de uso antes y después de la construcción reveló que el uso de pasos inferiores por los venados bura fue ligeramente mayor después de la construcción. No podemos atribuir completamente a los esfuerzos de mitigación el aumento de detecciones posteriores a la construcción, porque otros factores, como la disponibilidad del hábitat, la urbanización o la demografía, también pueden haber influido el uso de los pasos inferiores a lo largo de CA-71. En todo caso, incluso con la ampliación de la autopista y el subsecuente aumento en el volumen de tráfico, las estructuras de mitigación a lo largo de CA-71 sí permitieron el movimiento continuo y, por lo tanto, la conectividad a través de la ruta para los mamíferos grandes.

Roads can negatively affect biodiversity directly and indirectly (Forman and Alexander, 1998; Forman, 2003; Coffin, 2007). Direct effects of roads include loss of habitat, a decrease in quality of adjacent habitat, mortality of wildlife, and the creation of barriers to movement of animals (Forman, 2003). Because roads are the main network for human travel across the landscape, indirect effects include the facilitation of urban and agricultural development and, in general, the expansion of the human network and associated anthropogenic disturbance. Species of large mammals requiring broad areas, such as ungulates and carnivores, are especially susceptible to negative effects of roads (Fahrig and Rytwinski, 2009). In addition, large mammals often have low rates of reproduction and population growth, exist in relatively low densities, and are particularly vulnerable to persecution by humans, which can further exacerbate the consequences of mortality and of roads as barriers (Noss et al., 1996).

To offset the negative impact of roads on wildlife, a variety of measures for mitigation have been implemented (Forman, 2003). Specifically, crossing structures for wildlife combined with wildlife fencing can be successful at reducing mortality and reducing the effect of roads as barriers (Clevenger and Waltho, 2000; Clevenger et al., 2001; Forman, 2003). Evaluation of mitigative measures is critical to determine their effectiveness for conserving connectivity, and it is important to maximize inferential strength of these evaluative types of studies (Roedenbeck et al., 2007; Fahrig and Rytwinski, 2009). Few studies have assessed changes in movement of wildlife before and after installation of mitigative structures. One possible approach to achieve this goal is a before-after-control-impact design, which has been applied in environmental impact studies but is uncommon in road ecology (Roedenbeck et al., 2007; Fahrig and Rytwinski, 2009).

Southern California, an area where the natural landscape is highly fragmented by urbanization and roads, is one of the most populous areas of the United States (Beier et al., 2006). This region has been identified as a hotspot of biodiversity consisting of numerous endemic species juxtaposed with human development, thus creating a center of endangerment and extinction of species (Myers, 1990; Dobson et al., 1997; Myers et al., 2000). Previous research in the region has targeted large mammals as a focal group to study the effects of roads and urban fragmentation on movement of animals and landscape connectivity (Crooks, 2002; Tigas et al., 2002; Riley et al., 2003; Ng et al., 2004; Riley et al., 2006; Ruell et al., 2009). Along California State Route 71 (CA-71) through the Chino Hills southeast of Los Angeles, two studies in particular evaluated movement of carnivores around and across the roadway from 1997–2000 (Haas, 2000; Lyren, 2001). Haas (2000) found that measurable characteristics of the road influenced frequency and probability of use of underpasses and culverts by bobcats (*Lynx rufus*) and coyotes (*Canis latrans*). Lyren (2001) showed that use of culverts by coyotes was negatively correlated to peak periods of traffic.

In 2005, to facilitate increased flow of traffic, the California Department of Transportation added a northbound and a southbound lane to a 4-km segment of CA-71, thereby expanding the highway and lengthening some culverts that had previously supported movement of carnivores (Haas, 2000; Lyren, 2001). In addition, during the expansion, the California Department of Transportation incorporated multiple measures of mitigation recommended by Haas (2000) and Lyren (2001). These measures included the installation of two span bridges where culverts previously existed, wildlife fencing, and concrete center-dividers as well as restoration of native vegetation around culverts and underpasses for wildlife. Importantly, adjacent segments of CA-71 that were studied by Haas (2000) and Lyren (2001) were not modified during the construction in 2005.

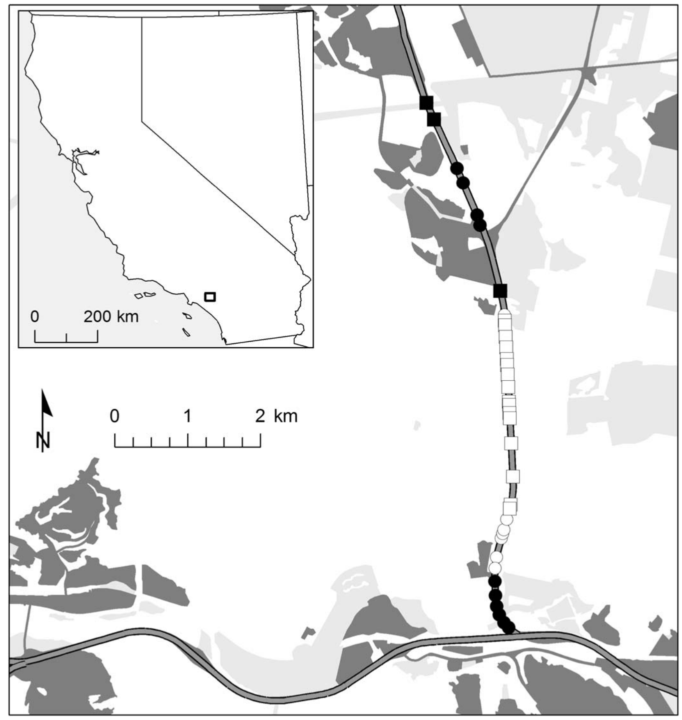

Fig. 1—Study area along an 8-km segment of California State Route 71 in southern California. Squares indicate underpasses sampled before and after expansion and mitigation of the highway and used in analyses; circles indicate underpasses not used in analyses. Solid squares and circles indicate underpasses located in the control zone, and open squares and circles indicate underpasses located in the impact zone. Background includes urban (dark gray), altered (light gray), and natural (white) classifications of land-use.

We took advantage of the expansion and mitigation of CA-71 and prior studies of wildlife along this roadway (Haas, 2000; Lyren, 2001) to study an impacted area and a control area before and after construction. Our objective was to quantify how the expansion of CA-71 and implementation of mitigative measures affected movement of large mammals across the roadway. We evaluated the possible impacts of expansion and connectivity mitigation on use of underpasses by bobcats, coyotes, and mule deer (*Odocoileus hemionus*) using data from cameras prior to and following construction in 2005.

Materials and Methods—Our study area was located southeast of Los Angeles along an 8-km north-south portion of CA-71 between Pine Avenue and California State Route 91, including a 4-km segment where CA-71 was widened in 2005 (Fig. 1). The freeway delineated two large blocks of habitat that differed in topography and type of vegetation, and that changed between our two study periods of November 1997–January 2000 (before expansion and mitigation) and August 2008–September 2009 (after expansion and mitigation). To the east of CA-71, Prado Flood Control Basin was relatively flat and, during November 1997–January 2000, dominated by riparian vegetation and nonnative eucalyptus forest, with some smaller amounts of nonnative annual grassland. By August 2008–September 2009,

Table 1—Characteristics (height, length, width, and type), modifications, and use by large mammals for 19 underpasses along California State Route 71 sampled before (1997–2000) and after (2008–2009) construction and mitigation in impact (with expansion and mitigation) and control (without alteration) zones along the state route southeast of Los Angeles, California. Underpasses are ordered to represent spatial arrangement on landscape from north to south. Use of underpasses by bobcats, coyotes, and mule deer assessed by detections with remote cameras stationed at entrances of underpasses, presented as indices of number of detections divided by sampling effort.

Underpass	Height (m)	Length (m)	Width (m)	Type of underpass[a]	Zone	Modification of underpass	Bobcat		Coyote		Mule deer[b]	
							Before	After	Before	After	Before	After
71-24	4.57	87.00	5.79	Arch	Control	None	0.000	0.015	0.824	1.215	0.000	0.000
71-25	1.80	64.00	2.13	Small box	Control	None	0.000	0.108	0.472	0.300	—	—
71-27	1.80	65.00	1.80	Pipe	Control	None	0.022	0.249	0.322	0.237	—	—
71-01	1.20	45.75	1.80	Small box	Impact	Extended 5.92 m	0.089	0.137	0.172	0.396	—	—
71-02	1.05	40.83	1.05	Pipe	Impact	Extended 4.25 m	0.010	0.081	0.034	0.136	—	—
71-03	1.05	42.51	1.05	Pipe	Impact	Extended 3.50 m	0.000	0.052	0.008	0.160	—	—
71-04	3.77	35.06	4.30	Large box	Impact	Extended 5.30 m	0.022	0.161	0.565	0.440	0.000	0.416
71-05	1.05	61.02	1.05	Pipe	Impact	Extended 2.50 m	0.000	0.047	0.013	0.040	—	0.020
71-06	1.05	63.76	1.05	Pipe	Impact	Extended 0.36 m	0.021	0.069	0.051	0.052	—	—
71-07	1.05	60.96	1.05	Pipe	Impact	None	0.058	0.016	0.085	0.032	—	—
71-08	13.00	25.20	21.71	Span	Impact	Replaced two structures	0.054	0.076	0.126	0.109	0.000	0.058
71-10	1.05	60.96	1.05	Pipe	Impact	None	0.007	0.038	0.081	0.011	—	—
71-11	1.05	46.33	1.05	Pipe	Impact	None	0.000	0.074	0.053	0.095	—	—
71-12	1.05	48.77	1.05	Pipe	Impact	None	0.031	0.210	0.000	0.004	—	0.029
71-13	1.05	33.44	1.05	Pipe	Impact	Extended 1.75 m	0.043	0.068	0.043	0.004	—	—
71-14	14.00	23.30	22.39	Span	Impact	Replaced two structures	0.049	0.092	0.093	0.088	0.000	0.112
71-16	1.50	121.92	1.50	Pipe	Impact	None	0.064	0.281	0.035	0.306	—	0.020
71-17	1.50	112.17	1.50	Pipe	Impact	None	0.018	0.112	0.036	0.184	—	—
71-18	4.57	44.94	5.84	Arch	Impact	None	0.000	0.116	0.099	0.156	0.197	0.366

[a] Span bridge (span), large arch culvert (arch), concrete box-culvert >2.5 m (large box), concrete box-culvert <2.5 m (small box), and reinforced concrete pipe and corrugated metal-pipe culvert (pipe).

[b] Data listed for five underpasses large enough for mule deer and, thus, included in the analyses with the exceptions of underpasses 71-05, 71-12, and 71-16, which were detections of approaches rather than use.

restoration of habitat in the Prado basin resulted in removal of much of the eucalyptus forest next to CA-71 and replacement with native coastal sage scrub, leaving primarily riparian vegetation with some coastal sage scrub, eucalyptus forest, and nonnative annual grassland. To the west of CA-71, steep hills and valleys characterized the Chino Hills. Before expansion and mitigation, habitat on the western side of CA-71 was predominantly invasive annual grassland with some native coastal sage scrub. This habitat burned in the Freeway Complex wildfire in November 2008. Post-fire and post-construction, much of the habitat in Chino Hills was barren, with a few pockets of invasive annual grassland and coastal sage scrub.

In 2005, the California Department of Transportation widened a 4-km segment of CA-71 on the western side of the freeway to accommodate a new northbound and a new southbound lane, thereby expanding the freeway from two to four lanes. Before expansion, there were 25 potential crossing structures under CA-71 in the 4-km impact zone. During expansion, seven of those structures were lengthened by 0.36–5.92 m (Table 1). As mitigation for expansion of the highway, two span bridges (71-08, 71-14; Table 1) were installed during construction specifically to enhance wildlife connectivity. Each bridge replaced a pair of culverts vertically stacked on top of each other in each location. Thus, the creation of the two span bridges removed four culverts, for a total of 23 underpasses in the impact zone after construction. Most structures for the entire 8-km study area were reinforced concrete pipes (60.6% of 36 structures), but they also included corrugated metal pipes (11.3%), bridges (11.3%), reinforced concrete boxes (8.5%), and arch culverts (8.5%).

As further mitigation, the California Department of Transportation fenced the entire length of the impact zone using wildlife fencing 3-m high with a mesh 10 × 15 cm and restored native vegetation around crossing structures in the impact zone. Finally, center-dividers on the highway were upgraded from guardrails to concrete dividers in the impact zone to prevent animals from attempting surface crossings. We defined 3 km north and 1 km south of the impact zone on CA-71 as a control zone because the roadway and the 13 possible crossing structures under it were not altered by the expansion or mitigation.

We sampled activity of large mammals at potential crossing structures with remotely-triggered cameras placed perpendicular to the path of an animal entering or exiting underpasses to evaluate their use the structures. Targeted species were bobcat, coyote, and mule deer. We considered all detections of animals by cameras at underpasses as an indication of use of underpasses. Because mule deer are ca. 1-m tall at the shoulder (Anderson and Walmo, 1984) and we detected deer at some underpasses too small to support their movement, we evaluated activity for this species at underpasses >2.5 m in height, the minimum recommended height for use by mule deer (Gordon and Anderson, 2004; Clevenger and Huijser, 2011).

Prior to expansion and mitigation, remotely-triggered film cameras (Camtrakker; CamTrak South Inc., Watkinsville, Georgia) were placed on the western side of CA-71 at 21 of 36 crossing structures, 18 located in the impact zone, and three located in the control zone, from November 1997–January 2000 (Haas, 2000; Lyren, 2001). After expansion and mitigation of the road, remotely-triggered digital cameras (Cuddeback Expert; NonTypical Inc., Park Falls, Wisconsin) were placed at entrances to underpasses on the western (Chino Hills) and eastern (Prado Basin) sides of the freeway. These cameras sampled 18 of 23 structures in the impact zone and 10 of 13 structures in the control zone from August 2008–September 2009.

In total, 19 structures (16 in the impact zone, three in the control zone) were monitored before and after construction and were included in the analyses. These structures included the two span bridges that replaced four previous structures in two locations and the seven structures in the impact zone that were lengthened during expansion of the road (Table 1). We assumed that the ability of cameras to detect faunal activity at underpasses was similar between the models of cameras used before and after construction because previous experience in the field showed both models to be reliable.

Because fewer crossing structures were sampled prior to expansion and mitigation and those structures were only sampled with a single camera on the western side of CA-71, we used the data from the same camera-locations at those 19 structures that were sampled before and after construction (Table 1). We calculated an index of relative activity from the photographic data for bobcats and coyotes by dividing the number of detections of a species at a specific camera-station by the number of nights (=camera-nights) sampled at that same camera-station (George and Crooks, 2006). We used this index as a measurement of use of underpasses for our analysis. Because our data did not meet the assumption of normality and our design was unbalanced, we could not use two-way repeated-measures analysis of variance most commonly associated with the before-after-control-impact design (Green, 1993; Smith, 2002; Roedenbeck et al., 2007). Instead, we used a series of nonparametric tests to evaluate differences in use of underpasses before and after expansion and mitigation as well as between the control and impact zones. For before-and-after comparisons of use of underpasses by bobcats and coyotes, we conducted two analyses for each species using Wilcoxon signed-rank tests. First, we paired the location of the underpass for all 19 underpasses in the impact and control zones and then restricted the analyses to the 16 underpasses in the impact zone; small sample size precluded before-and-after comparisons within the control zone. For comparisons of use of underpasses between the control and impact zones, we conducted two analyses for each species using Wilcoxon-Mann-Whitney rank-sum tests, first comparing the control and impact zones before construction and then comparing the control and impact zones after construction.

For mule deer, only four sampled underpasses (71-24 in control zone; 71-04, 71-14, and 71-18 in impact zone; Table 1) met the minimum recommended height (>2.5 m) to support movement of deer (Gordon and Anderson, 2004; Clevenger and Huijser, 2011) prior to expansion and mitigation. Due to construction, one of those four underpasses (71-04) was lengthened by 5.3 m, and a span bridge (71-14) replaced another where two vertically stacked culverts previously existed; the other two underpasses (71-24, 71-18) were not modified. Two other vertically stacked underpasses too small to support movement of deer before construction were replaced by the second span bridge (71-08), resulting in five underpasses sampled after construction that were potentially large enough for deer to use (71-24 in control zone; 71-04, 71-08, 71-14, and 71-18 in impact zone; Table 1). The small number of underpasses that were candidates for movement of deer precluded comparisons of use of underpasses by deer between treatment and control zones as well as before-and-after comparisons separately for each zone. Consequently, we used a Wilcoxon signed-rank test to evaluate if indices of relative activity for deer differed before and after construction, pooling structures among the treatment and control zones and pairing on the locations of five underpasses after construction.

Results—Before expansion of the road and mitigation, remote cameras installed at the 19 focal underpasses recorded 415 photographs of coyotes at 18 underpasses (15 impact, three control), 125 photographs of bobcats at 13 underpasses (12 impact, one control), and 30 photographs of mule deer at one underpass (one impact, zero control) in 3,442 camera-nights (Table 1). After expansion and mitigation, cameras stationed at the same locations recorded 1,139 photographs of coyotes at all 19 underpasses, 511 photographs of bobcats at all 19 underpasses, and 419 photographs of mule deer at four of the five underpasses considered as candidates for use by mule deer (four impact, zero control) in 4,950 camera-nights (Table 1). Cameras also recorded 14 photographs of deer at three impacted underpasses (71-05, 71-12, and 71-16; Table 1) that were 1.05–1.50 m in height. However, these few detections were of approaches rather than evidence of use of underpasses by mule deer.

For bobcats, indices of relative activity were higher after construction than before construction for all 19 underpasses in the impact and control zones (Wilcoxon signed-rank $W = 5$, $P < 0.001$) and for the 16 underpasses in the impact zone when analyzed separately from the control ($W = 4$, $P < 0.001$; Fig. 2a). Use of underpasses by bobcats, however, did not differ between the impact and control zones either before (Wilcoxon-Mann-Whitney $U = 12.5$, $n = 16$ impact, $n = 3$ control, $P = 0.211$) or after ($U = 25$, $n = 16$ impact, $n = 3$ control, $P = 0.958$) construction (Fig. 2a). In contrast, indices of relative activity for coyotes were higher in the control than in the impact zone before (Wilcoxon-Mann-Whitney $U = 46$, $n = 16$ impact, $n = 3$ control, $P = 0.008$) and after ($U = 42$, $n = 16$ impact, $n = 3$ control, $P = 0.047$) construction (Fig. 2b). Use of underpasses by coyotes did not differ, however, before or after construction for all 19 underpasses pooled (Wilcoxon signed-rank $W = 71$, $P = 0.353$) or for the 16 underpasses in the impact zone ($W = 43$, $P = 0.211$; Fig. 2b). A nonsignificant trend suggested that

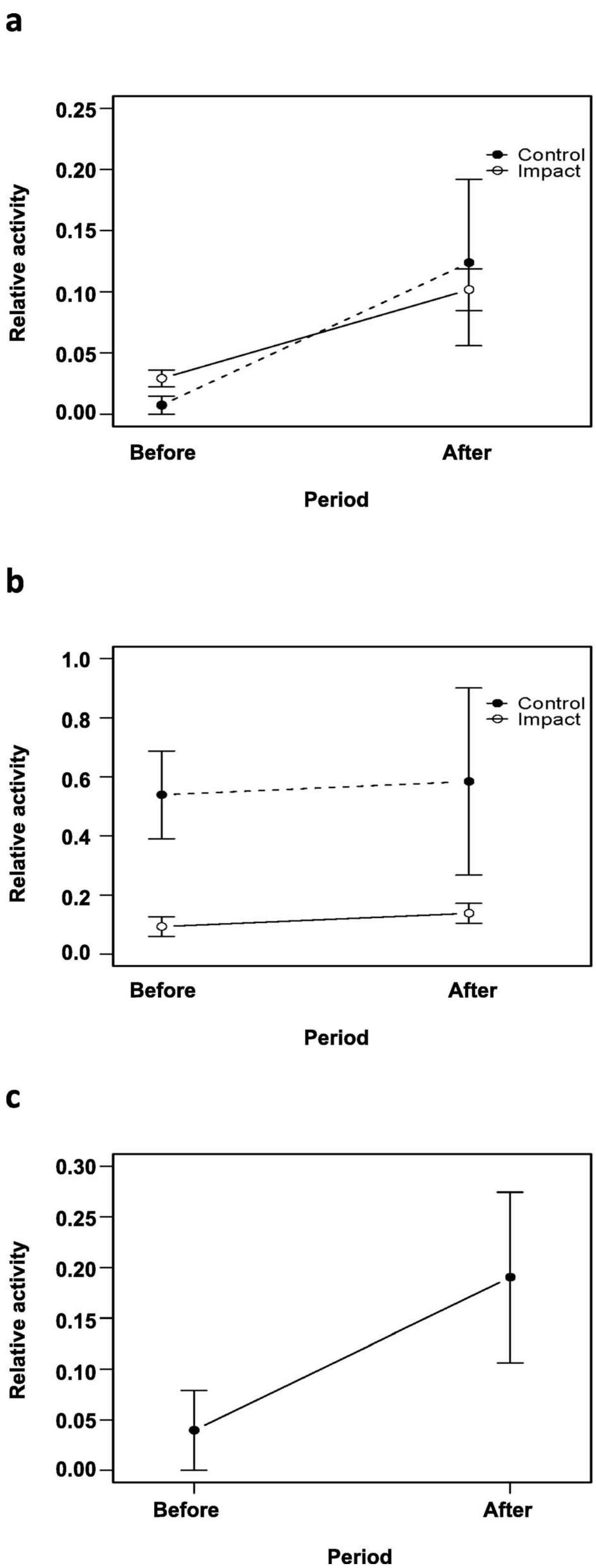

Fig. 2—Interaction plots (means ±1 *SE*) for a) bobcats (*Lynx rufus*), b) coyotes (*Canis latrans*), and c) mule deer (*Odocoileus hemionus*) showing use of underpasses in control and impact zones before (1997–2000) and after (2008–2009) construction and mitigation along California State Route 71 in southern California.

indices of relative activity for deer were higher after the expansion and mitigation than before the project for all five underpasses available for use by deer (Wilcoxon signed-rank $W = 0$, $P = 0.100$; Fig. 2c).

Discussion—We detected an increase in use of underpasses by bobcats after the expansion and mitigation of CA-71 compared to before, for all underpasses pooled together and specifically for those in the impact zone. We cannot, however, fully attribute this increased activity solely to the mitigative efforts, particularly because use of underpasses in the control zone appeared to increase as well (Fig. 2a). The increase in detections of bobcats after construction could have resulted from a variety of factors. It may reflect an increase in the size of populations of bobcats throughout the study area since the initial survey before expansion and mitigation, although densities of populations before and after construction are unknown. The Freeway Complex wildfire in November 2008 also could have contributed to increased activity of bobcats along the roadway. This fire extended through the Chino Hills due west of CA-71 and our control and impact zones, and it destroyed most of the available habitat throughout the area. As a result, quality habitat for bobcats was limited to a relatively narrow area immediately adjacent to CA-71, potentially increasing movement of bobcats around and across the roadway. Nonetheless, regardless of what factors contributed to increased movement along CA-71, the mitigative measures did at least support greater usage of underpasses and, thus, movement of bobcats between the Chino Hills and Prado Basin, despite increased width of the road and volume of traffic along the roadway after construction. Annual average daily volume of traffic throughout our study area increased 59.4% after construction, from 34,500 before construction to 55,000 after construction (California Department of Transportation, http://traffic-counts.dot.ca.gov/). The fact that this large increase in the amount of traffic did not noticeably reduce use of underpasses by bobcats and, hence, movement between the Chino Hills and Prado Basin could be considered a successful outcome of the mitigation.

In contrast to bobcats, use of underpasses by coyotes did not considerably differ before and after the expansion and mitigation. Results did suggest, however, that use of underpasses by coyotes was higher in the control zone, although sample size in the control was limited. In particular, coyotes used one underpass in the control zone more frequently than any other structure in the study area during both sampling periods. This underpass was located directly next to a golf course, which likely supported a large source of prey for coyotes, and was a major contributor to the increased usage of the underpass in the control zone. Importantly, although we did not detect an increase in movement of coyotes in the impact zone after expansion and mitigation, we also did not detect a decrease in usage of underpasses by coyotes. This finding again suggests the mitigation was at least partially successful in allowing movement of carnivores to continue across the roadway.

Mitigation also seemed to facilitate increased movement of mule deer across CA-71 between the Chino Hills and Prado Basin. Prior to mitigation, we documented deer using only one underpass of four sufficiently large enough to support movement of deer. After mitigation, we documented deer using four of five underpasses large enough to support movement of deer. Specifically, deer were recorded using the two span bridges (71-08 and 71-14) installed during mitigation, whereas movement of deer had not been detected in the four culverts at those two locations prior to the project. Further, a large box-culvert not used by deer prior to expansion and mitigation was used after construction, and the underpass that deer did use prior to construction underwent an 85.5% increase in usage by deer after construction. Only one large underpass, located at the northern limit of our study area in the control zone, did not support movement of deer before or after the expansion and mitigation. A relatively high amount of urbanization around this underpass likely contributed to this pattern, because mule deer have been known to avoid areas with human development and favor underpasses with more natural habitat (Nicholson et al., 1997; Ng et al., 2004). In the period after construction, we detected deer a total of 14 times at three underpasses that we expected were too small (<2.5 m in height) for use by deer; these images showed deer near the underpasses but not entering or exiting these structures. We again cannot fully attribute the trend of increased activity of deer to the mitigation, and it is likely that a number of factors contributed to this pattern, including concurrent restoration of habitat in the Prado Basin that may have improved quality of habitat for deer along the roadway.

In addition to apparently facilitating increased use of underpasses by our targeted species across CA-71, mitigation also likely reduced mortality of wildlife due to vehicles on the roadway. Prior to expansion and mitigation, Lyren (2001) documented mortality of 21 coyotes and one bobcat during ca. 30 months of monitoring for carcasses on CA-71 in 1997–2000; most of these mortalities were in sections along the highway where wildlife fencing was not present. After expansion and mitigation, we documented mortality of seven coyotes, one bobcat, and one mule deer during ca. 28 months of monitoring for carcasses on CA-71 during 2008–2010. Interestingly, as was the case before mitigation, most of these mortalities were detected in areas without wildlife fencing, including near the interchanges of CA-71 and California State Route 83 and CA-71 and California State Route 91. This spatial pattern of mortality suggests the wildlife fencing was effective at reducing mortality of wildlife on roads and that additional fencing should be considered in places where it is absent. We conclude that even with the expansion of the freeway and subsequent lengthening of seven underpasses and substantial increase in speed and volume of traffic, mitigation along CA-71 did allow for continued movement of large mammals, and hence connectivity, across the roadway. In this case, the expansion of CA-71 demonstrates that it is feasible to include connectivity mitigation for wildlife within existing plans to upgrade or maintain roads.

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